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Effect of Pr Additions to Li-doped Bi2212 Bulk Superconductors Sintered at Low Temperature

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Abstract

The physical properties study of the $Bi_2Sr_2CaCu_2O_y$ (Bi2212) ceramics samples sintered at low temperature has been carried out by measurement of electrical resistance and powder X-ray diffraction (XRD). The effects of Pr doping on the formation process of the Bi2212 phase, and its structural and superconducting features were studied. The samples were prepared by a solid-state reaction method from oxides and carbonate powders. The samples with nominal composition $Bi_{2.12}Sr_{1.90}Ca_{1.02}Cu_{1.96}Li_{0.15}Cl_{0.15}O_y$ added with praseodymium oxide (Pr_2O_3) were sintered in air at 710°C. The Pr_2O_3 addition ranging between 0.1mass% and 1.2mass% promotes the formation of the Bi2212 phase in low temperature synthesis. The full-width at half maximum (FWHM) value of the (200) and (00$\underline{1}$0) XRD peaks is slightly decreasing in the samples for low level doping and reaches a minimum around 0.6mass%. The maximum zero resistance temperature (T_c) is observed at 82.5K for the sample with 0.6mass% Pr_2O_3 addition by sintering even at 710°C, which is about 150°C lower than that of the non-added Bi2212 phase.

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Keywords: Low temperature synthesis; Bi2212 bulk superconductor; $LiClO_4$ and Pr_2O_3 addition; Zero resistance

1. Introduction

The $Bi_2Sr_2CaCu_2O_y$ (Bi2212) superconductor is known to be one of the most stable compounds among the copper oxide-based high-T_c superconductors. In the last 25 years, chemical substitution and/or addition to the Bi2212 superconductors has been widely studied, because it is expected to improve its superconducting properties and to

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influence its formation processes. It has been revealed that the addition of some elements, Li, Cl and Pr to Bi2212 system enhances Bi2212 phase formation and superconducting properties [1-6]. In general, lower temperature synthesis is desirable for commercial production of this important material. Noro et al. [2] reported that the X-ray diffraction (XRD) pattern of $Bi_{2.12}Sr_{1.90}Ca_{1.02}Cu_{1.96}Li_{0.15}Cl_{0.15}O_y$ compounds sintered at 720°C shows the predominance of the Bi2212 phase. Then, the zero resistance of the sample is observed at 78K. Aloysius et al. [6] reported that the critical current density (J_c) and the zero resistance temperature (T_c) of the (Bi, Pb)-2212 system is highly enhanced upon the addition of Pr. However, no further studies have yet been made to clarify the effect of Pr addition on the physical properties of Bi2212 bulk samples sintered at low temperature. In this work, we study the effect of Pr additions on the T_c and the full-width at half maximum (FWHM) values of the (200) and (00$\underline{10}$) XRD peaks for Bi2212 bulk samples sintered at low temperature, in comparison with that of non-added sample.

2. Experimental

The Bi2212 bulk samples were prepared by a conventional solid-state reaction with a nominal composition of $Bi_{2.12}Sr_{1.90}Ca_{1.02}Cu_{1.96}Li_{0.15}Cl_{0.15}O_y$ [7]. Raw materials of $SrCO_3$ (99.9%), $CaCO_3$ (99.9%) and CuO(99.9%) were mixed and calcined twice at 950°C for 20h in air. After grinding, the calcined powder was mixed with Bi_2O_3 (99.9%), $LiClO_4$ (98.0%) and various amounts of Pr_2O_3 (99.9%). The mixtures were pelletized using a cylindrical die of 13mm diameter under a force of 30 kN. The Pr added samples were sintered at T_s=710°C for 100h in air. The sintering temperatures of other samples were described later. Finally, the samples were annealed at 700°C for 20h and rapidly quenched in liquid nitrogen, to ensure optimum value of the oxygen concentration. All the products were examined at room temperature by powder XRD using Cu-Kα radiation (Rigaku Ultima IV). The measurements were carried out with the θ-2θ scanning method in the range of 2θ = 20-65°. The chemical compositions of the sample were measured by wavelength-dispersive X-ray fluorescence spectrometry (WDXRF; Rigaku ZSX-Primus III). The electrical resistance R was measured by a standard DC four-probe method at temperatures between 50 and 290K.

3. Results and discussion

3.1. Effect of $LiClO_4$ and Pr_2O_3 addition

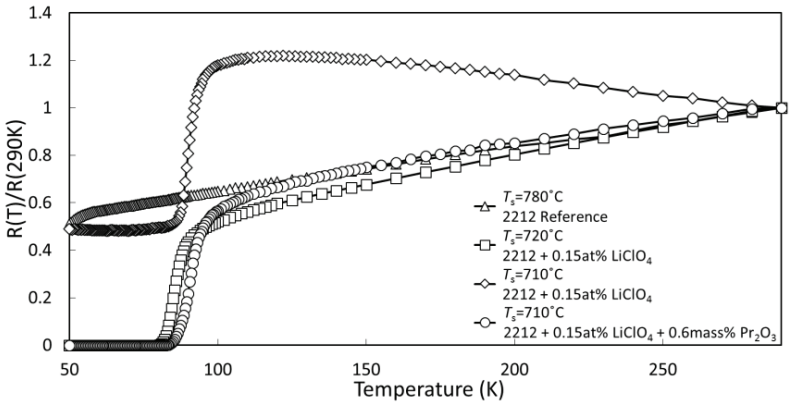

Fig. 1. Temperature dependence of the normalized resistance R(T)/R(290K) for 0.15at% $LiClO_4$ and 0.6mass% Pr_2O_3 added sample sintered at 710°C, 0.15at% $LiClO_4$ added samples sintered at 710 and 720°C, and reference (non-added) sample sintered at 780°C.

A comparison of the R-T behavior of $LiClO_4$ and Pr_2O_3 added sample, $LiClO_4$ added sample and non-added sample is shown in Fig. 1. The T_c (R=0) value is 82.5K for $LiClO_4$ and Pr_2O_3 added sample sintered at T_s=710°C. In addition, the T_c value is 78K for $LiClO_4$ added sample sintered at T_s=720°C. On the other hand, zero resistance is not observed above 50K and the resistance variation is found to be non-metallic from room temperature down to

transition for Li-doped sample without Pr_2O_3 that was sintered at T_s=710°C. And, no superconducting transition has been obtained above 50K for reference sample (non-added sample) sintered at T_s=780°C [2]. Therefore, the addition of $LiClO_4$ and Pr_2O_3 is effective for the enhancement of superconducting properties of Bi2212 samples sintered at low temperature. These results mean that the phase formation temperature of Bi2212 phase decreased with Li, Cl and Pr additions.

3.2. Pr_2O_3 content dependence of zero resistance temperature T_c

The Pr_2O_3 content dependence of the T_c (R=0) value for the samples sintered at T_s=710°C is shown in Table 1. As can be seen, the addition of a proper amount of Pr_2O_3 enhances the superconducting properties. The T_c of the Pr_2O_3 added samples ranging between 0.4mass% and 1.0mass% is more than 80K. The T_c value is increasing in the Pr added sample for low level doping and reaches a maximum around 0.6mass%. Then, the T_c value is decreasing when the Pr_2O_3 content is further increasing for higher doping level. No superconducting transition has been obtained for $LiClO_4$ and Pr_2O_3 added sample sintered at T_s=700°C.

Table 1. The T_c value versus the amount of Pr_2O_3 content (T_s=710°C).

Pr_2O_3 content (mass%)	0.1	0.4	0.5	0.6	0.8	1.0	1.2
T_c (K)	78.0	81.5	81.5	82.5	80.5	80.0	77.5

3.3. FWHM and T_c

A comparison of XRD patterns of the sample with 0.15at% $LiClO_4$ and 0.8mass% Pr_2O_3 addition sintered at 710°C, and the reference sample (non-added sample sintered at 860°C) is shown in Fig. 2. It is confirmed that Bi2212 phase forms at 710°C though it has poor crystallinity. The main XRD peaks of the Li and Pr added sample sintered at 710°C can be indexed in accordance with the Bi2212 structure with lattice parameters a=5.38Å, b=5.34Å and c=30.99Å. The chemical composition of the sample measured by WDXRF is Bi : Sr : Ca : Cu = 2.12 : 1.97 : 1.02 : 1.86.

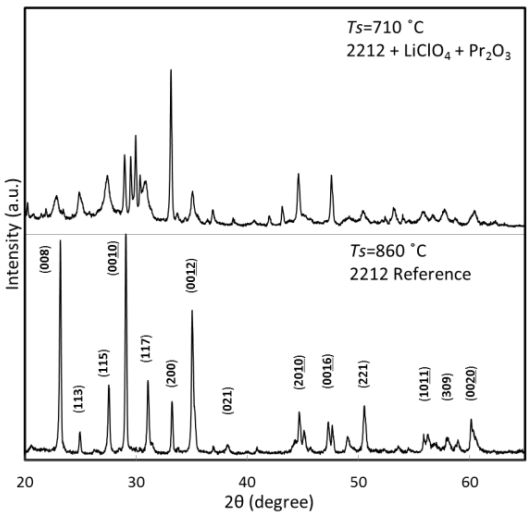

Fig. 2. XRD patterns of the sample with 0.15at% $LiClO_4$ and 0.8mass% Pr_2O_3 addition sintered at 710°C, and non-added sample sintered at 860°C.

The values of T_c and FWHM for the samples sintered at T_s=710°C are shown in Fig. 3 as a function of Pr_2O_3 content. The FWHM values of the (200) and (00$\underline{10}$) XRD peaks are more than 0.150° for the Pr added samples

studied here. On the other hand, the FWHM values of the (200) and (00$\underline{10}$) XRD peaks of the reference sample sintered at 860°C are 0.100° and 0.107° respectively. It is confirmed that the crystallinity is directly influenced by the sintering temperature. The FWHM values of the (200) and (00$\underline{10}$) XRD peaks are slightly decreasing in the samples for low level doping and reaches a minimum around 0.6mass%. Then, the FWHM values increase when the Pr_2O_3 content is more than 1.0mass%. It can be said that the sample has poor crystallinity in higher doping region. As seen from Fig. 3, the T_c value is increasing in the Pr_2O_3 added samples for low level doping and reaches a maximum around 0.6mass%. Then, the T_c value is decreasing when the Pr_2O_3 content is further increasing for higher doping level. The maximum T_c=82.5K is observed for the sample with 0.6mass% Pr_2O_3 addition.

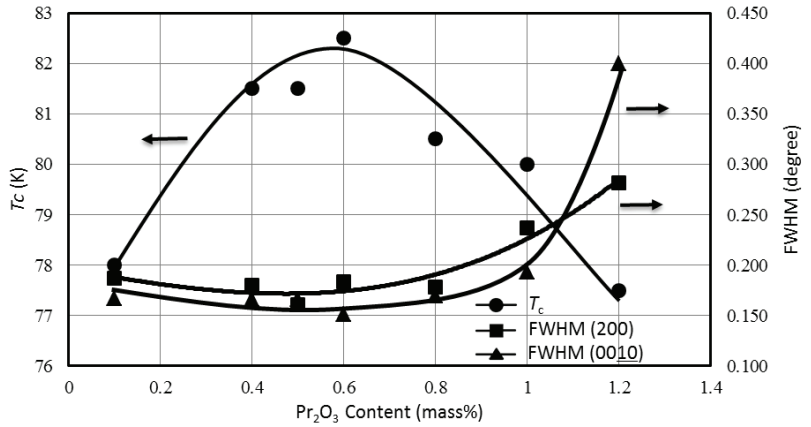

Fig. 3. The values of T_c and FWHM as a function of Pr_2O_3 content (T_s=710°C).

4. Conclusion

The superconducting properties of $Bi_{2.12}Sr_{1.90}Ca_{1.02}Cu_{1.96}Li_{0.15}Cl_{0.15}O_y$ added with praseodymium oxide (Pr_2O_3) compounds sintered in air at 710°C have been investigated by measurement of electrical resistance and XRD. The T_c of the Pr_2O_3 added samples ranging between 0.1mass% and 1.2mass% is more than liquid nitrogen temperature, but no transition has been obtained above 50K for non-added Bi2212 samples sintered at the same temperature. The XRD pattern of the sample with Pr_2O_3 addition shows the predominance of the Bi2212 phase. The Pr_2O_3 addition promotes the formation of the Bi2212 phase in low temperature synthesis such as 710°C though they have poor crystallinity. The zero resistance of the sample with 0.6mass% Pr_2O_3 addition is observed at 82.5K. Therefore, a small amount Pr_2O_3 addition to the Li-doped Bi2212 bulk superconductors sintered at low temperature is effective for the enhancement of superconducting properties.

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